

ITRAC-2:

2nd Advanced Training Course on Illicit Trafficking and Radiological Consequences with NUCLEONICA, ITU Karlsruhe, 22-24th April 2009

Nucleonica Data Centre
(www.nucleonica.net)

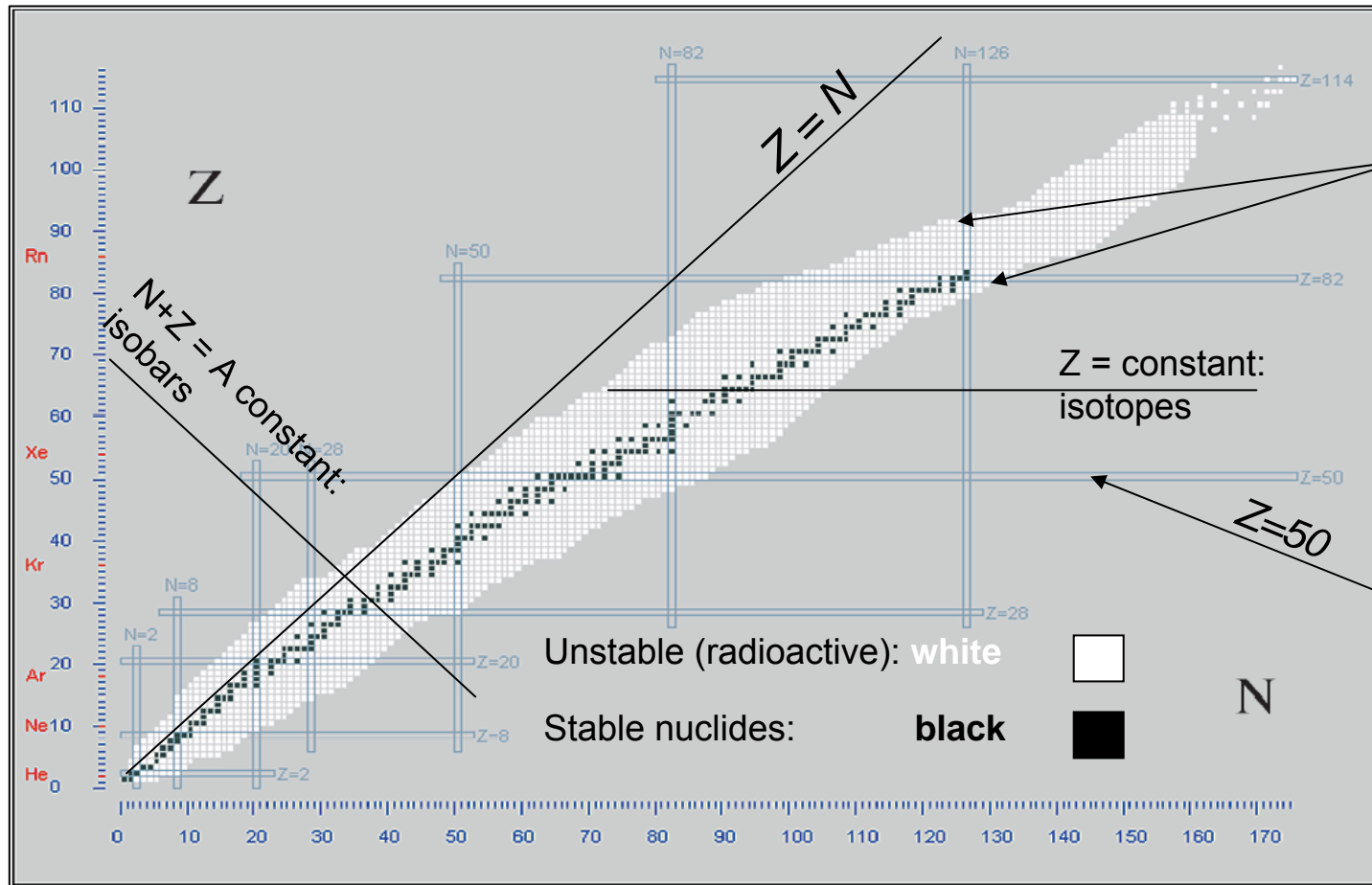
J. MAGILL

*European Commission, Joint Research Centre,
Institute for Transuranium Elements,
Postfach 2340, 76125 Karlsruhe, Germany*



It all started with the Karlsruhe Nuclide Chart...





Extremities of the white regions are known as the proton and neutron drip-lines

Nuclei with even numbers of protons and neutrons are more stable. The stability is extremely significant for special numbers of protons and neutrons i.e. 2, 8, 20, 28, 50, 82, and 126. These are the **magic numbers**

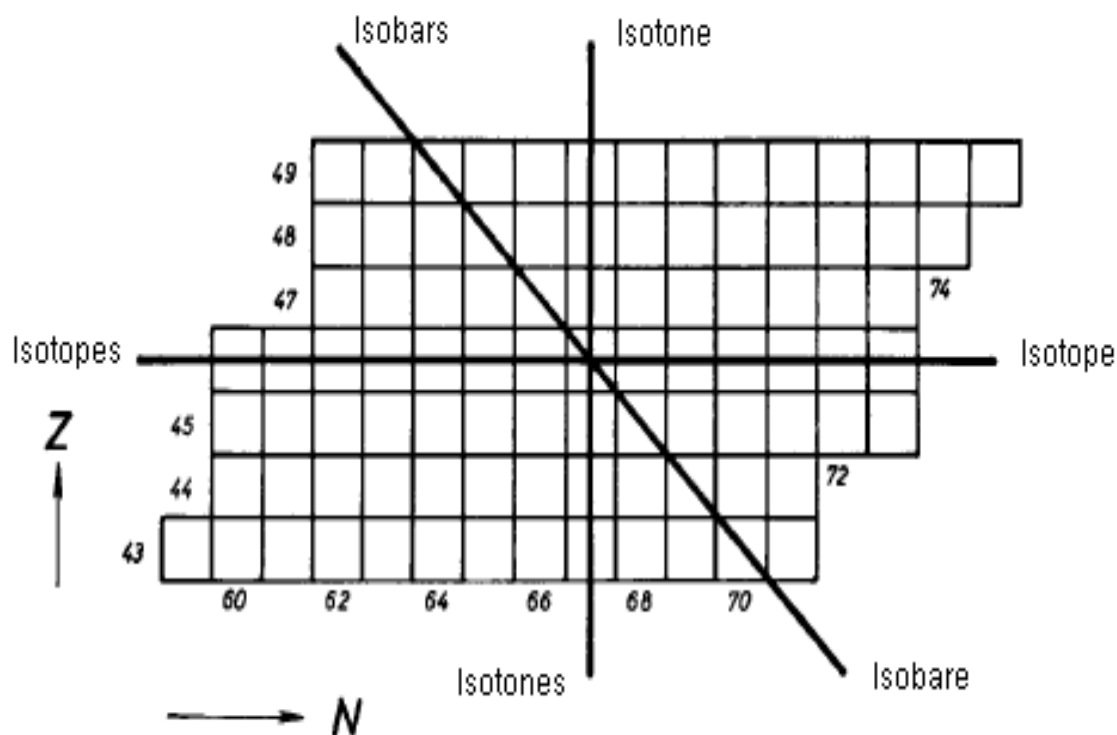
For light nuclei, $N = Z$, but with increasing Z , $N > Z$, i.e. the number of neutrons increases more strongly than the number of protons. Note that the stable isotopes lie within a relatively narrow range indicating that the neutron to proton ratio must have a certain value or range to be stable

Nuclide : *A type of atom specified by its atomic number, Z , mass number, A , and energy state.*

Isotopes : *meaning at the same place in the periodic table ➡ nuclides with same Z .*

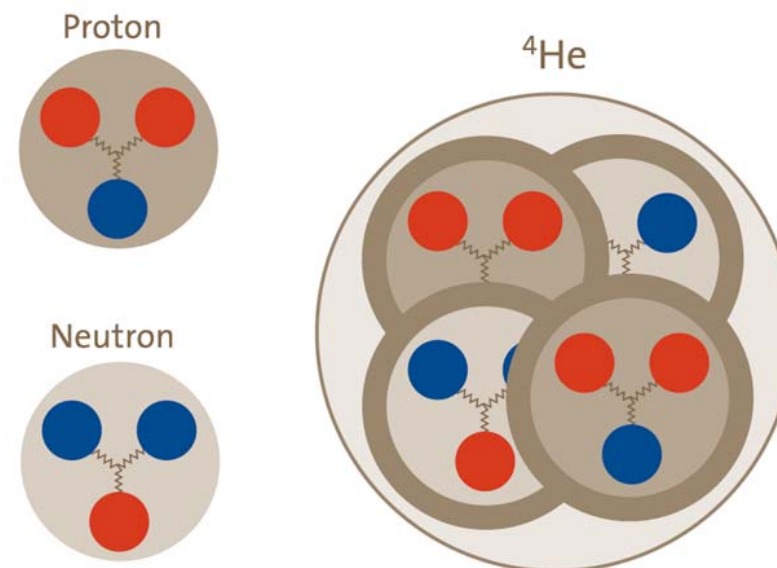
Isotones : *nuclides with the same $N (=A-Z)$.*

Isobars : *nuclides with the same A .*



The Quark Structure of Nuclei

Quarks were proposed independently by Gell-Mann and Zweig in 1964 as the basic building blocks of matter. The word "quark" was coined by Gell-Mann based on the sound made by ducks. Later, he discovered the use of the word quark in James Joyce's book *Finnegan's Wake*.



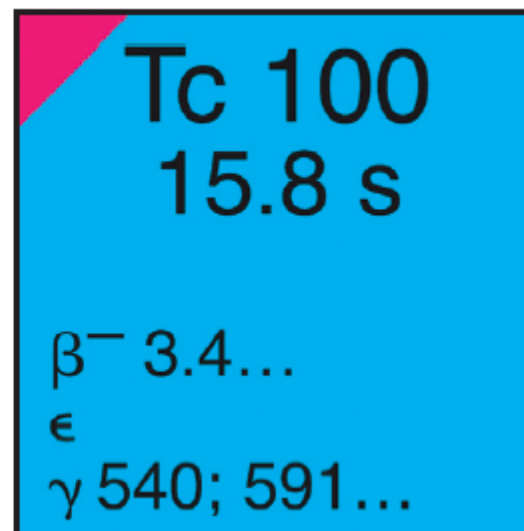
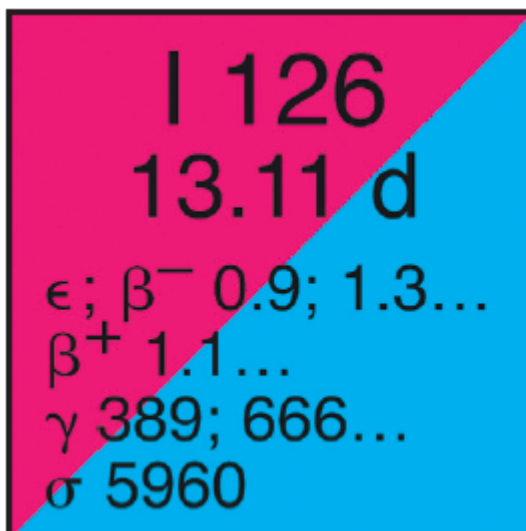
The quark structure of nucleons: the proton consists of two up quarks (red) and one down quark (blue) and the neutron one up and two down quarks held together by powerful gluon fields. (Right) the overlap of protons and neutrons in a helium-4 nucleus based on the static sizes of particles © American Physical Society, 2003.

Use of colours in the Karlsruhe Nuclide Chart:

Already in the first Edition of the Karlsruhe Chart of the Nuclides, colours were used to indicate the decay modes

black = stable nuclide;
yellow = α -decay;
red = β^+ decay or electron capture;
blue = β^- decay;
white = isomeric transition).

Bi 207 31.55 a ϵ β^+ ... γ 570; 1064; 1770...	Bi 208 $3.68 \cdot 10^5$ a ϵ γ 2615	Bi 209 100 $1.9 \cdot 10^{19}$ a α 3.137 σ 0.011 + 0.023 $\sigma_{n,\alpha} < 3E-7$
Pb 206 24.1 σ 0.027	Pb 207 22.1 σ 0.61	Pb 208 52.4 σ 0.00023 $\sigma_{n,\alpha} < 8E-6$
Tl 205 70.48 σ 0.11	Tl 206 3.7 m γ 686; 453; 216; 256; 1021... β^- 1.5... γ (803...)	Tl 207 1.33 s γ 1000; 351 β^- 1.4... γ (898...)



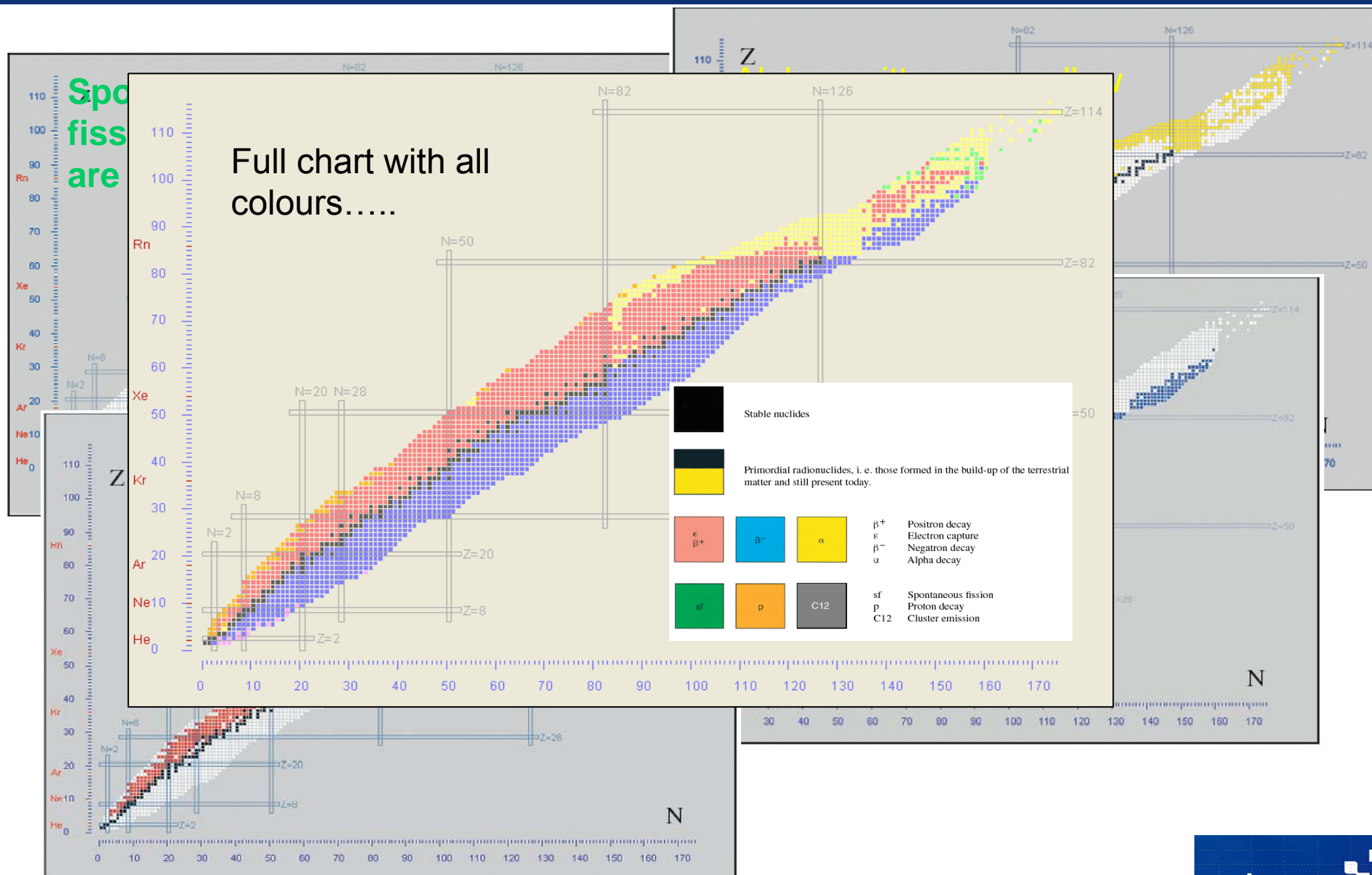
When a nuclide has more than one decay mode, coloured triangles give a rough indication of the branching ratios of each mode.

Left: The large triangles used in I-126, indicate the branching ratios for electron capture ϵ and β^- emission are $\geq 5\%$, but $\leq 95\%$ respectively.

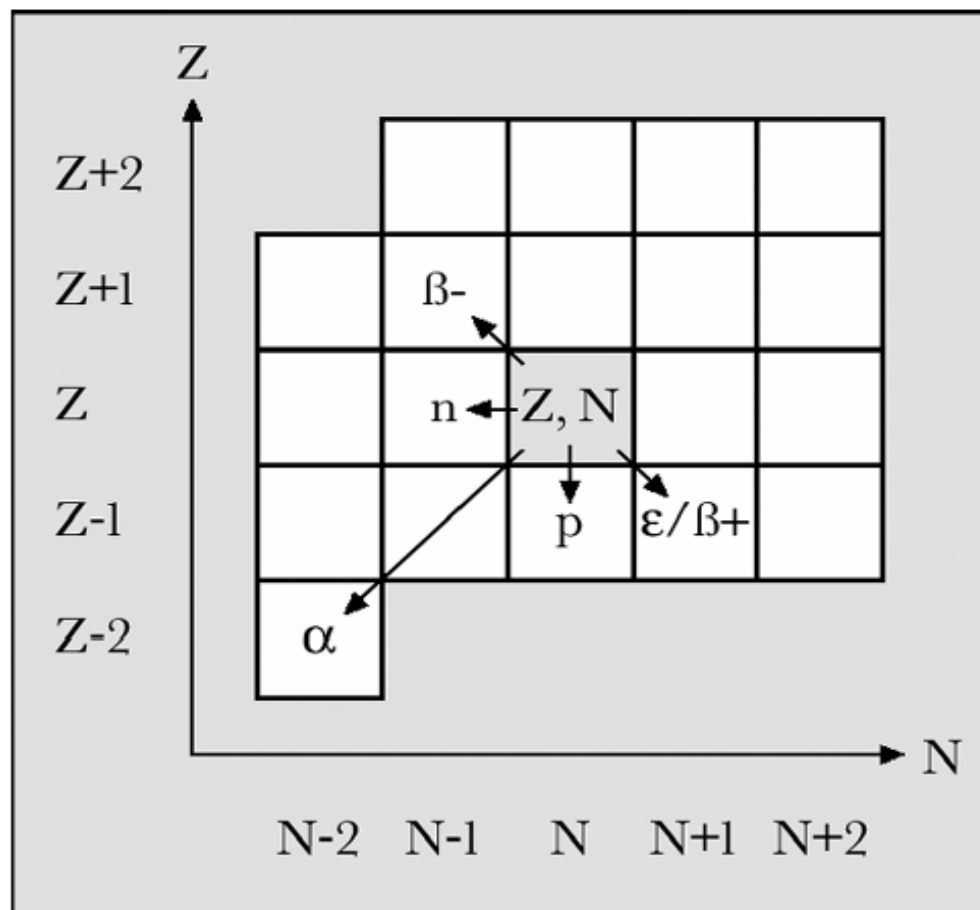
Note that the decay modes are listed in the order of decreasing frequency.

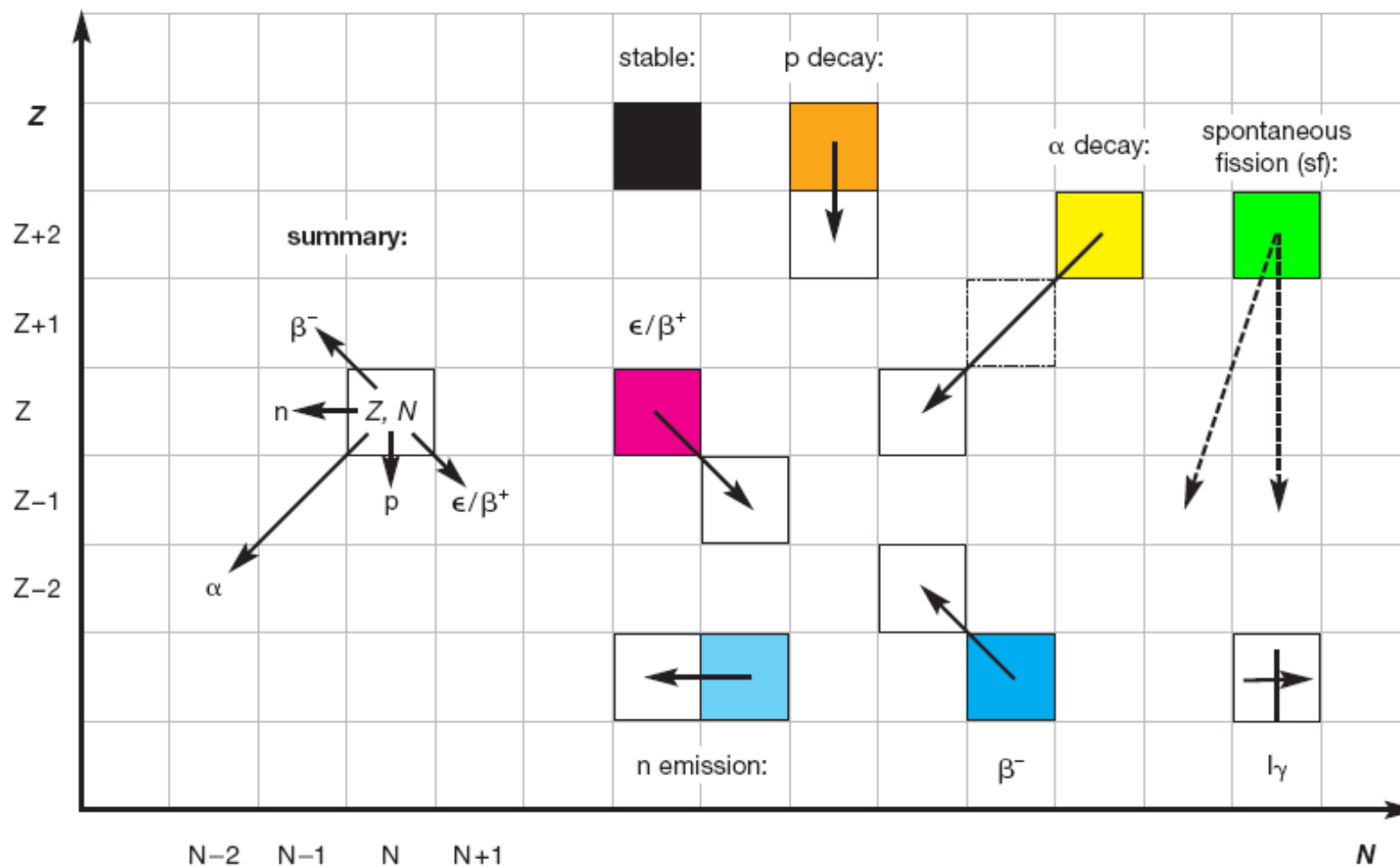
Right: The small triangle used in Tc-100 indicates that the ϵ branching ratio is $\leq 5\%$. The corresponding branching ratio for β^- emission $\geq 95\%$.

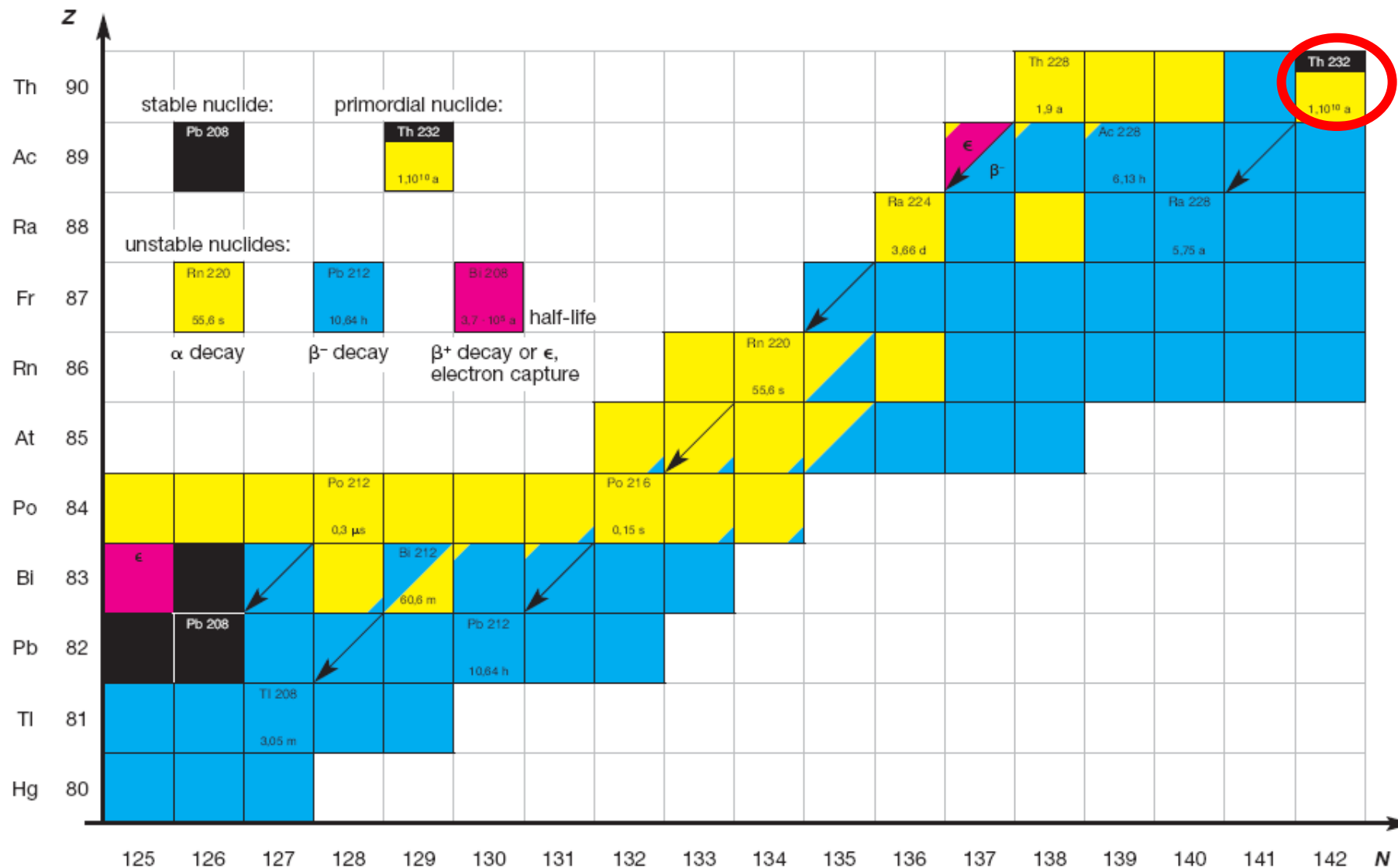
			7		N 14.0067 $\sigma_{abs} 2.00$	N 10 2.3 MeV $200 \cdot 10^{-24} s$ p ?	N 11 ~0.77 MeV ? $\sim 590 \cdot 10^{-24} s$? p	N 12 11.0 ms $\beta^+ 16.4... \gamma 4439... \beta\alpha 0.2...$	N 13 9.96 m $\beta^+ 1.2$ no γ	N 14 99.636 $\sigma 0.080$ $\sigma_n, p 1.93$	N 15 0.364 $\sigma 0.00004$	
			6		C 12.0107 $\sigma 0.0035$	C 8 230 keV $2.0 \cdot 10^{-21} s$ 2p	C 9 126.5 ms $\beta^+ 15.5... \beta\alpha 8.24; 10.92 \beta\alpha$	C 10 19.3 s $\beta^+ 1.9... \gamma 718; 1022$	C 11 20.38 m $\beta^+ 1.0$ no γ	C 12 98.93 $\sigma 0.0035$	C 13 1.07 $\sigma 0.0014$	C 14 5730 a $\beta^+ 0.2$ no γ
			5		B 10.811 $\sigma_{abs} 760$	B 7 1.4 MeV $350 \cdot 10^{-24} s$ p	B 8 770 ms $\beta^+ 14.1... \beta\alpha - 1.6; 8.3$	B 9 0.54 keV $800 \cdot 10^{-21} s$ p	B 10 19.9 $\sigma 0.3$ $\sigma_n, \alpha 3840$ $\sigma_n, p 0.007$	B 11 80.1 $\sigma 0.005$	B 12 20.20 ms $\beta^+ 13.4... \gamma 4439... \beta\alpha 0.2...$	B 13 17.33 ms $\beta^+ 13.4... \gamma 3684 \beta n 3.6; 2.4...$
4		Be 9.012182 $\sigma 0.0088$			Be 6 92 keV $5 \cdot 10^{-21} s$ 2p	Be 7 53.29 d $\alpha 478$ $\sigma_n, \alpha 39000$	Be 8 6.8 eV $67 \cdot 10^{-18} s$ $\alpha 0.046$	Be 9 100 $\sigma 0.0088$	Be 10 $1.6 \cdot 10^9 a$ $\beta^+ 0.6$ $\sigma < 0.001$	Be 11 13.8 s $\beta^+ 11.5... \gamma 2125; 6791... \beta\alpha 0.77...$	Be 12 23.6 ms $\beta^+ 11.7... \beta n$	
3		Li 6.941 $\sigma_{abs} 71$			Li 4 5.0 MeV $91 \cdot 10^{-24} s$ p	Li 5 1.23 MeV $370 \cdot 10^{-24} s$ p	Li 6 7.59 $\sigma 0.039$ $\sigma_n, \alpha 940$	Li 7 92.41 $\sigma 0.045$	Li 8 840.3 ms $\beta^+ 12.5$ $\beta\alpha - 1.6$	Li 9 178.3 ms $\beta^+ 13.6... \beta n 0.7...$	Li 10 230 keV $2.0 \cdot 10^{-21} s$ n	Li 11 8.5 ms $\beta^+ - 18.5; 20.4 \gamma 3368^+; 320... \beta n; \beta 2n; \beta 3n; \beta\alpha; \beta t; \beta d$
2		He 4.002602 $\sigma_{abs} < 0.05$			He 3 0.000134 $\sigma 0.00005$ $\sigma_n, p 5330$	He 4 99.999866	He 5 648 keV $700 \cdot 10^{-24} s$ n	He 6 806.7 ms $\beta^+ 3.5$ βd	He 7 159 keV $2.9 \cdot 10^{-21} s$ n	He 8 119 ms $\beta^+ 9.7... \gamma 981; 478^+ \beta n; \beta t$	He 9 65 keV $7 \cdot 10^{-21} s$ n	He 10 0.17 MeV $2.7 \cdot 10^{-21} s$ 2n
1		H 1.00794 $\sigma 0.332$	H 1 99.9885 $\sigma 0.332$	H 2 0.0115 $\sigma 0.00051$	H 3 12.323 a $\beta^+ 0.02$ $\sigma < 0.000008$	H 4 3.28 MeV $139 \cdot 10^{-24} s$ n	H 5 1.9 MeV ? $240 \cdot 10^{-24} s$? 2n	H 6 1.6 MeV $290 \cdot 10^{-24} s$ n ? 3n ?	H 7 20 MeV $23 \cdot 10^{-24} s$ 2n ?	8		
				n 1 10.25 m $\beta^+ 0.8$	8.40E-4 1.35E-3	0.01080 0.01420	0.1700 0.2190	2.67E-3 4.10E-3	0.73E-4 0.69E-4	0.41E-4 0.11E-3		
				1.71E-3 4.08E-3								
							4		6			



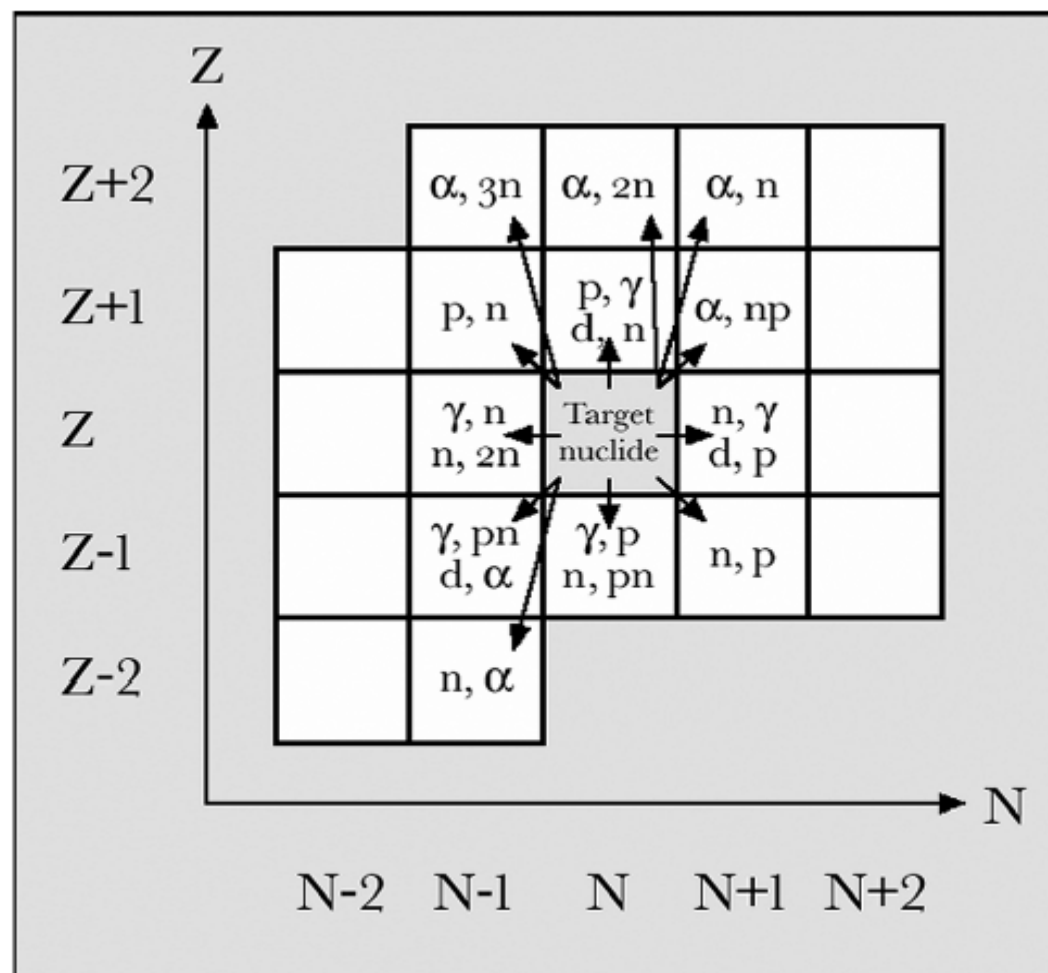
Nuclear decay processes on the nuclide chart. A nuclide with “co-ordinates” Z, N transforms to the nuclide Z', N' through the decay processes shown







Activation processes and nuclear reactions on the nuclide chart. A target nuclide with coordinates Z, N transforms to the nuclide Z', N' through the processes shown





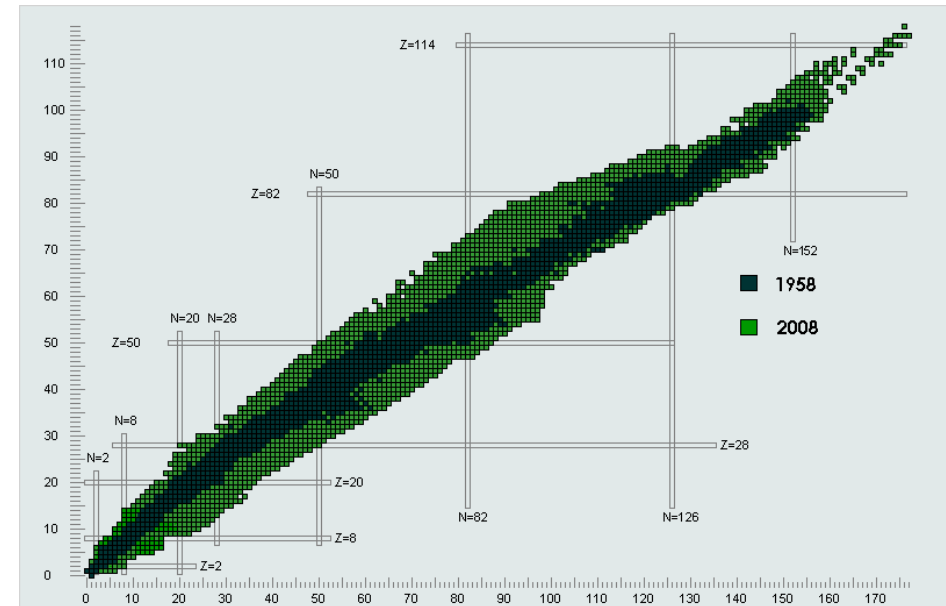
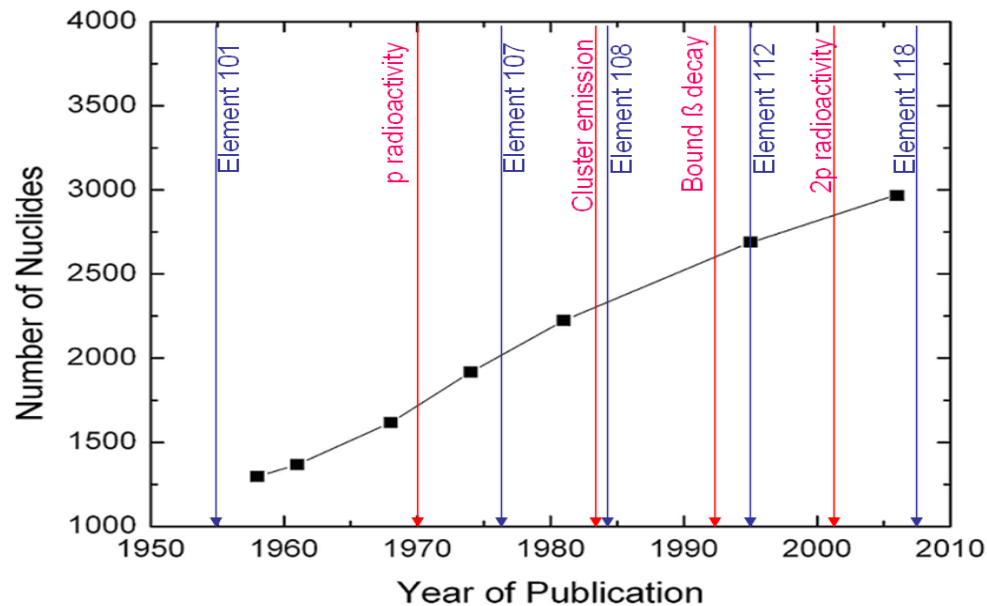
G.T. Seaborg, 1951



W. Seelmann-Eggebert
“El profesor alemán”

- ➔ Representation of nuclides in a proton/neutron map system (Fea 1935, Seaborg, 1940, Segrè 1945)
- ➔ 1958 first edition of the “Karlsruher Nuklidkarte” W. Seelmann-Eggebert and G. Pfennig from the Karlsruhe Radiochemical Institute.
- ➔ 267 stable and 1030 radionuclides for 4 decay modes

Number of Nuclides for the 7th edition: 2962 ground states and 692 isomers Progress in nuclear structure knowledge



Number of Nuclides in the KN editions

- Between the first edition and the 7th edition the number of nuclides has increased from 1300 to 3000. Theoretical predictions are expecting 6000 possible ground-state nuclides

<http://www.nuclides.net/>

Prehistoric Cave Art at Altamira

The most famous of the Altamira paintings are on the plafond - a low ceiling in one of the caves to the left from the entrance. The total area of the ceiling is about 100 m². Here the artist carefully combined pigment painting with the ceiling relief. The majority of more than 20 animal figures are bison: though there is also a horse, a boar and a deer.

The most common pigments used in these paintings were lead and Fe, Cu , black MnO_2 and charcoal. Rather than cladding the sample by traditional ^{14}C techniques of acid-alkali measurements (where sample requirements would damage the artwork), accelerator mass spectrometry was used to count individual carbon isotopes. This by reducing the amount of sample required is a minimum. To obtain the carbon needed for dating, a scalpel was used to scratch off approximately 20–40 mg from a dark section of the painting. Radiocarbon dating of the charcoal used to draw the horse is shown above. Based on the drawing to be 1400 \pm 400

Halo Nuclides

in which the neutron rich fermions splits into two doubly magic tin

How "constant" is the decay constant?

Can the nuclear decay "constant" be influenced under extreme conditions of temperature, pressure, etc.? Following the discovery of radioactivity, many attempts to modify decay rates were made by changing temperature, pressure, magnetic fields, and gravitational fields (temperature influences are on the basis of quantum tunneling). In one attempt, Rutherford actually used a bomb to produce temperatures of 10^6 °C and pressures of 1000 bar (about for a short period of time, no effect on the decay constant was observed).

The Superheavy Elements

The idea of the existence of a group of stable elements out with the main nuclear "island" dates back to the 1950s and received considerable attention in the 1960s. The location of a smaller island of stability at $Z=114$, $N=184$ was suggested in 1960. The isotope $Z=114$, $N=184$ has a doubly magic configuration with both the protons and neutrons being in completely stable

In the years 1991-94, the GSI group at Darmstadt, Germany, achieved the synthesis of elements 113 (Roßbach), 100 (Jensen), 102 (Wetterlin), 110 and 112 (see also article in 1995). A Russian team in Dubna, purchased for the first time element 114 by bombarding (fusing) nuclei of californium-249 with calcium-48. The scientists had to bombard the plutonium with calcium nuclei for a period of six weeks to produce a single nucleus of element 114. The compound nucleus of element 114 had the somewhat "long" half-life of 20 s before undergoing a cascade of alpha decays to element 110 over a time period of approximately 100 s.

Fusion: $\frac{90}{38}\text{Kr} + \frac{235}{92}\text{U} \rightarrow \frac{283}{130}\text{Xe} + 5$
 Decay: $\frac{283}{130}\text{Xe} \rightarrow \frac{283}{131}\text{I} \rightarrow \frac{283}{132}\text{Te} \rightarrow$
 $\frac{279}{132}\text{Te} + \alpha$

Nuclear waste disposal and natural analogues

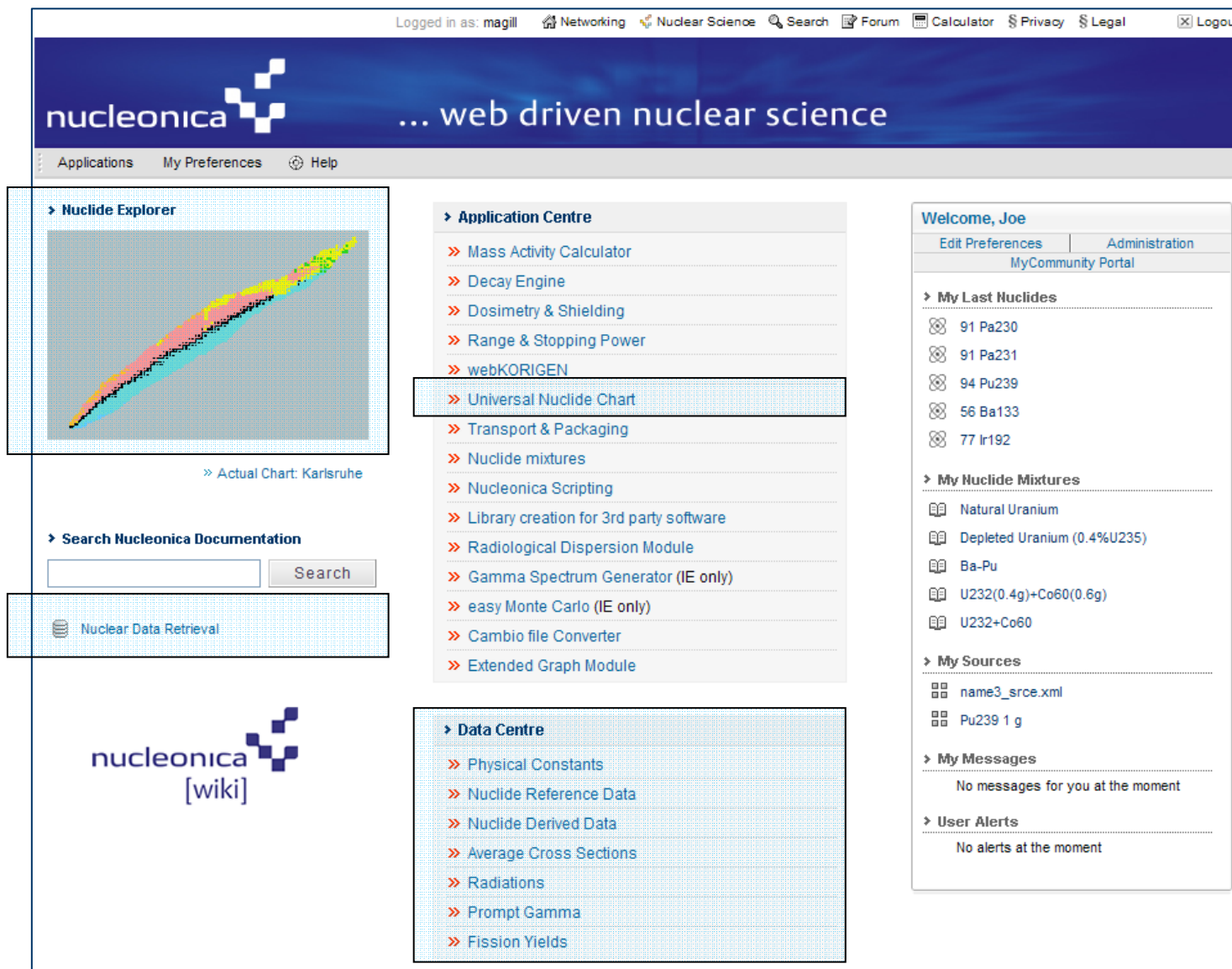
One of the challenges facing the nuclear industry is to demonstrate that an underground repository can contain nuclear waste safely for very long periods of time. One way of building confidence in engineered barriers is by studying the processes which operate in natural and archaeological systems and by making comparisons with systems with a repository. These studies are called "natural analogues." Natural analogues provide a way of informing the wider public on the principles on which repositories are built, without using complex mathematical demonstrations of "safety" and "risk."

- The Oklo natural fission reactors
The natural fission reactors at Oklo in Gabon, Africa can be considered as analogues for very old radioactive

- **Dunarobbia forest**
The Dunarobbia trees in Italy, which have been preserved in clay, are of relevance as repository contents since the wood is considered to be analogous to the organophilic/soluble materials which comprise a large part of the waste.

• The Nineteen Foss
In this natural rock arch, in south-west Scotland, mineralised veins of uranium are partly exposed. Pitchblende has undergone dissolution by leaching by acid rain. This location is ideal for investigating radionuclide migration.

Nucleonica Data Centre



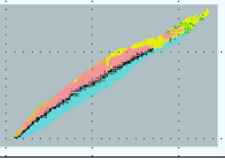
The screenshot displays the Nucleonica web application interface. At the top, a navigation bar includes links for Networking, Nuclear Science, Search, Forum, Calculator, Privacy, Legal, and Logout. The main header features the Nucleonica logo and the tagline "... web driven nuclear science". Below the header, a secondary navigation bar offers Applications, My Preferences, and Help.

The main content area is divided into several sections:

- Nuclide Explorer:** A section on the left containing a plot of nuclides (Actual Chart: Karlsruhe) and a search bar for Nucleonica Documentation.
- Application Centre:** A central list of applications, including Mass Activity Calculator, Decay Engine, Dosimetry & Shielding, Range & Stopping Power, webKORIGEN, **Universal Nuclide Chart** (highlighted), Transport & Packaging, Nuclide mixtures, Nucleonica Scripting, Library creation for 3rd party software, Radiological Dispersion Module, Gamma Spectrum Generator (IE only), easy Monte Carlo (IE only), Cambio file Converter, and Extended Graph Module.
- Data Centre:** A section at the bottom center listing data resources such as Physical Constants, Nuclide Reference Data, Nuclide Derived Data, Average Cross Sections, Radiations, Prompt Gamma, and Fission Yields.
- User Dashboard:** A right-hand panel for user "Joe" showing options to Edit Preferences or Administration, a list of last nuclides (91 Pa230, 91 Pa231, 94 Pu239, 56 Ba133, 77 Ir192), my nuclide mixtures (Natural Uranium, Depleted Uranium, Ba-Pu, U232+Co60), my sources, and messages/alerts.

At the bottom left, there is a link to the Nucleonica [wiki].

Nuclide Explorer



Actual Chart: Karlsruhe

Application Centre

- Mass Activity Calculator
- Decay Engine
- Dosimetry & Shielding
- Range & Stopping Power
- webKORIGEN
- Universal Nuclide Chart
- Transport & Packaging
- Nuclide mixtures
- Nucleonica Scripting
- Library creation for 3rd party software
- Radiological Dispersion Module
- Gamma Spectrum Generator (IE only)
- easy Monte Carlo (IE only)
- Cambio file Converter
- Extended Graph Module


Search Nucleonica Documentation

Nuclear Data Retrieval

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Data Centre

- Physical Constants
- Nuclide Reference Data
- Nuclide Derived Data
- Average Cross Sections
- Radiations
- Prompt Gamma
- Fission Yields



Physical Constants

Physical Constants
Conversion Factors
Prefixes / Greek Alphabet
Radiological Limits

Radiological Limits

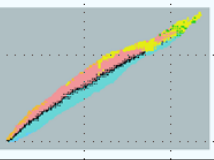
Workers
Apprentices and Students
Members of the Public

Workers

Dose Limits for exposed workers	Euratom	ICRP	IAEA	Germany
Limit on effective dose for exposed workers in a consecutive 5 years period:	100 mSv	20 mSv/y	20 mSv/y	20 mSv/y
Maximum effective dose in any single year:	50 mSv/y	50 mSv/y	50 mSv/y	50 mSv/y
Equivalent dose limit to the foetus, accumulated over the period of time between declaration of pregnancy to the delivery date:	1 mSv	2 mSv		1 mSv
Pregnant woman				2 mSv/m
Total work life (50 y)				400 mSv
Partial body exposure:				
Limit on equivalent dose for the lens of the eyes:	150 mSv/y	150 mSv/y	150 mSv/y	150 mSv/y
Limit on equivalent dose for the skin:	500 mSv/y	500 mSv/y	500 mSv/y	500 mSv/y
Limit on equivalent dose for the hands, forearms, feet and ankles:	500 mSv/y	500 mSv/y	500 mSv/y	500 mSv/y

Name
Alpha
Beta
Gamma
Delta
Epsilon
Zeta
Eta
Theta
Iota
Kappa
Lambda
Mu
Nu
Xi
Omicron

Nuclide Explorer



Actual Chart: Karlsruhe

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Nuclear Data Retrieval

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[wiki]

Data Centre

- Physical Constants
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- Average Cross Sections
- Radiations
- Prompt Gamma
- Fission Yields

Pu239
2.4E4 y

Fission Yields

94 Plutonium

Current Chart: Karlsruhe

Element: Mass:

Pu 239

Select Fission Yields

Library: JEFF-3.1

Type of Fission: Thermal fission

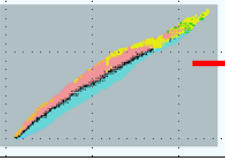
Total number of fission products: 25

	Nuclide	Half-life	Independent Yield	Error	Cumulative Yield	Error
Compare	55 Cs 135	2.3 (± 3) My	8.54E-05	3.04E-05	7.38E-02	2.36E-03
Compare	55 Cs 133	Stable	2.26E-07	8.21E-08	6.99E-02	1.26E-03
Compare	55 Cs 137	30.04 (± 3) y	4.57E-03	1.62E-03	6.59E-02	8.03E-04
Compare	55 Cs 138	33.41 (± 18) m	4.27E-03	1.44E-03	5.94E-02	1.61E-03
Compare	55 Cs 139	9.27 (± 5) m	2.30E-02	5.12E-03	5.72E-02	9.18E-04
Compare	55 Cs 140	1.062 (± 5) m	2.77E-02	4.64E-03	4.45E-02	1.12E-03
Compare	55 Cs 141	24.94 (± 6) s	2.92E-02	4.50E-03	3.38E-02	1.73E-03
Compare	55 Cs 142	1.70 (± 2) s	1.52E-02	3.67E-03	1.63E-02	2.48E-03
Compare	55 Cs 143	1.791 (± 7) s	5.95E-03	1.87E-03	6.06E-03	1.61E-03
Compare	55 Cs 138m	2.91 (± 8) m	6.06E-03	2.04E-03	6.06E-03	1.85E-03
Compare	55 Cs 144	994 (± 4) ms	5.69E-04	2.02E-04	8.62E-04	2.21E-04
Compare	55 Cs 136	13.03 (± 7) d	5.88E-04	2.07E-04	7.60E-04	2.15E-04
Compare	55 Cs 144m	1.0 (± 0) s	5.69E-04	2.02E-04	5.69E-04	1.99E-04
Compare	55 Cs 136m	19 (± 2) s	3.45E-04	1.21E-04	3.45E-04	1.21E-04
Compare	55 Cs 145	594 (± 13) ms	1.81E-04	6.42E-05	1.81E-04	6.38E-05
Compare	55 Cs 135m	53 (± 2) m	5.22E-05	1.86E-05	5.22E-05	1.86E-05

Graph

Nuclide Explorer...

Nuclide Explorer



Actual Chart: Karlsruhe

Application Centre

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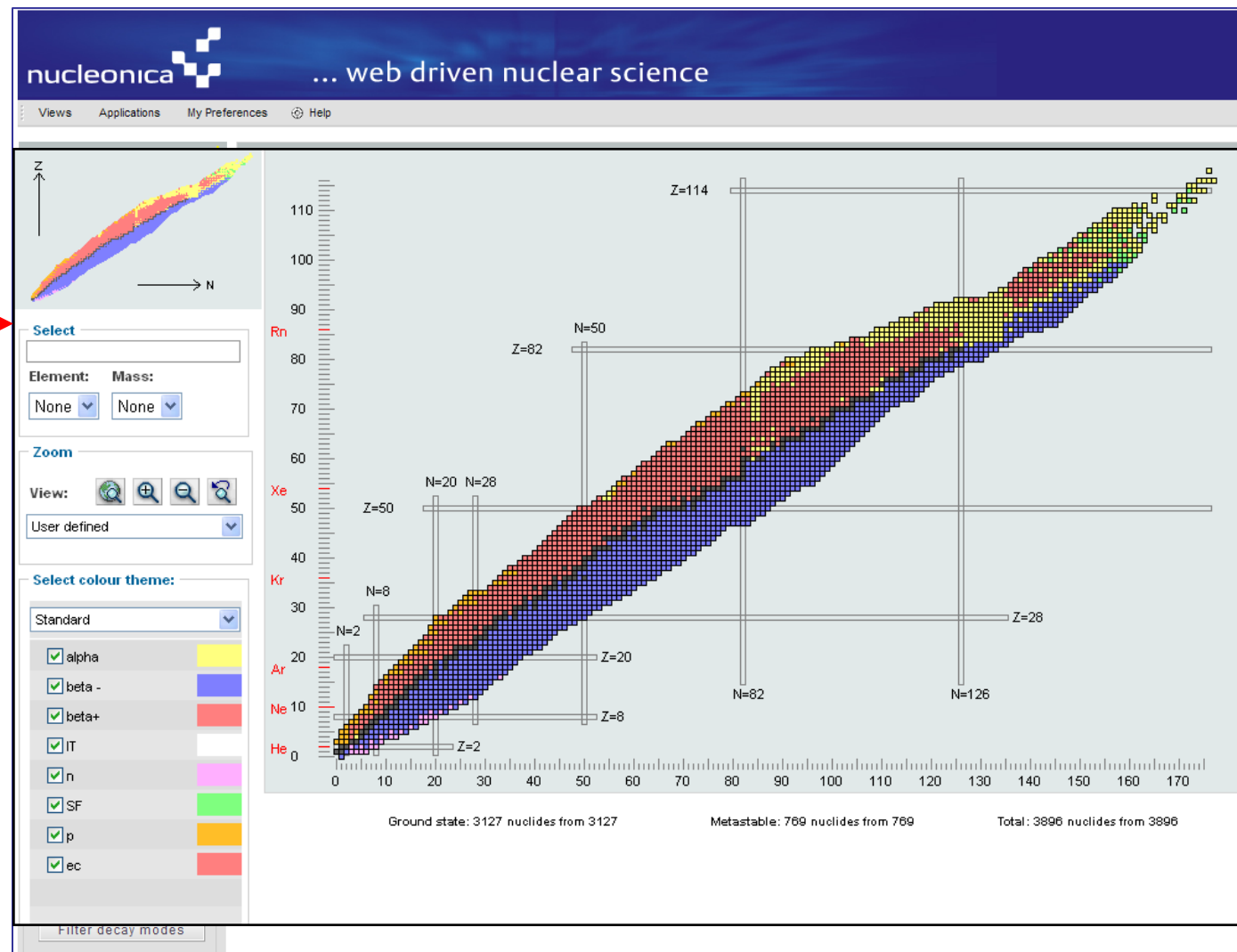
Search Nucleonica Documentation

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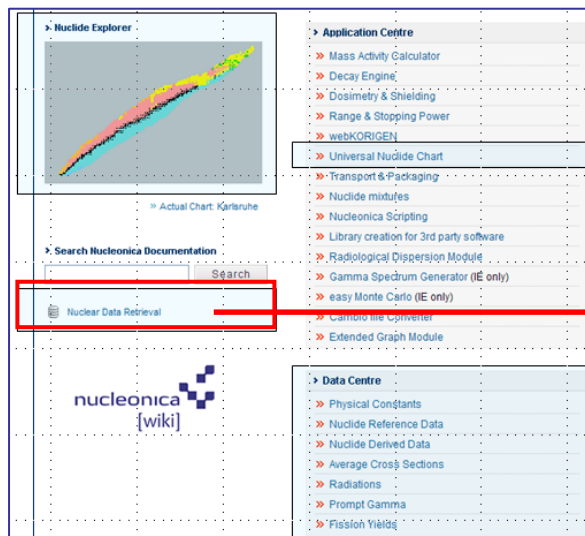
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Data Centre

- Physical Constants
- Nuclide Reference Data
- Nuclide Derived Data
- Average Cross Sections
- Radiations
- Prompt Gamma
- Fission Yields



Nuclear Data Retrieval...



Nucleonica Explorer

Actual Chart: Karlsruhe

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Nucleonica/JEFF-3.1 EGAF Prompt Gammas ICRP 8th Table of Isotopes

Select Database:

Nuclide Search **Radiation Search** **Advanced Search**

Radiation Search - Search Variables & Range

☒ Gamma and X-Rays Energy: +/- keV
☐ Alpha +/- keV
 +/- keV

Z: Element:

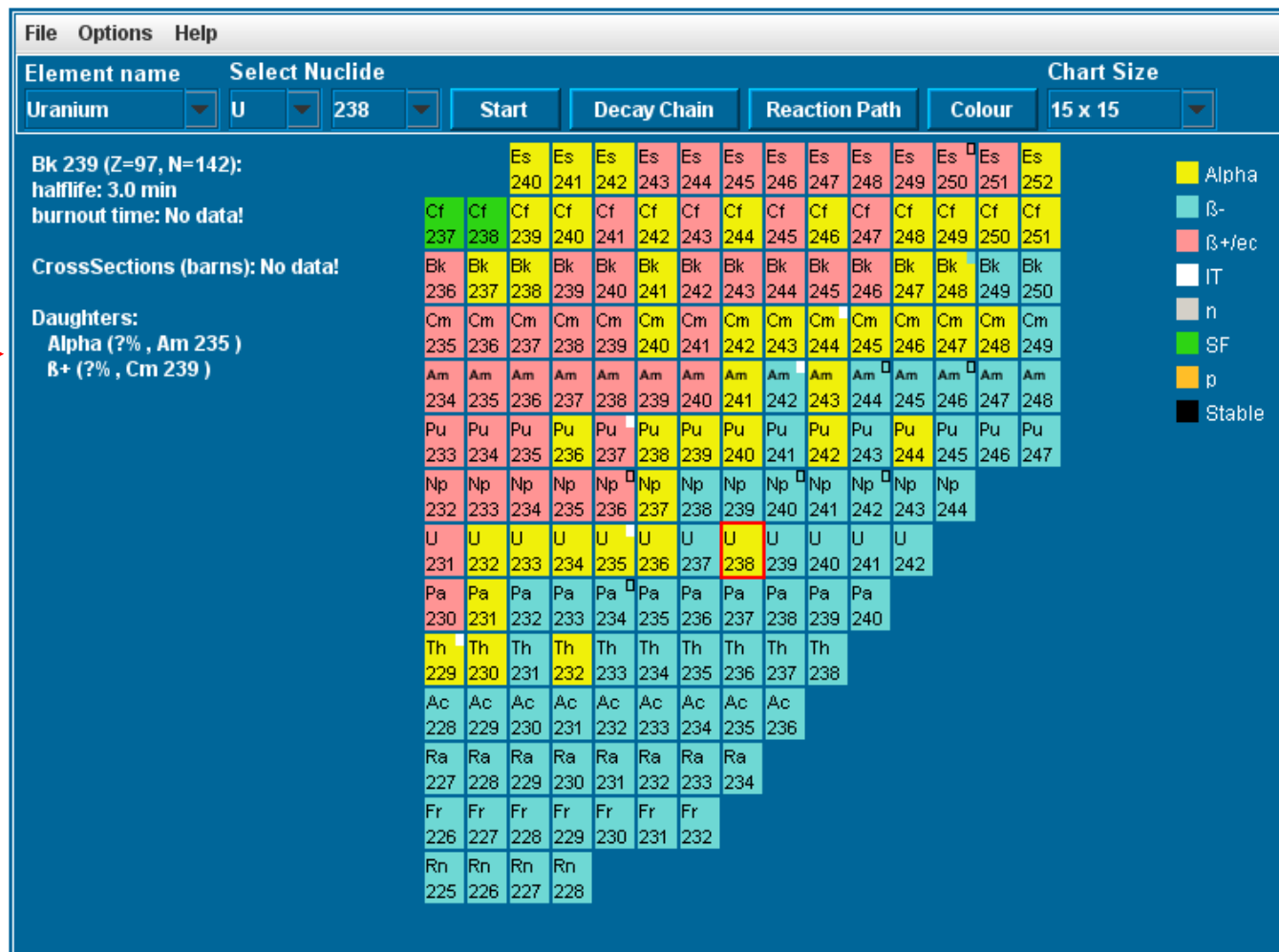
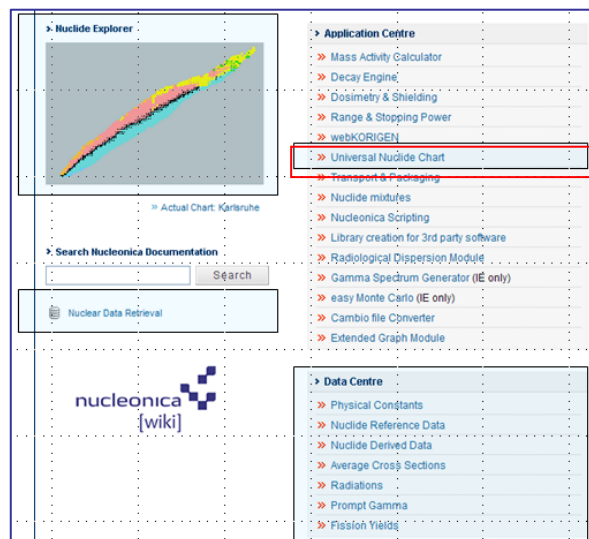
Mass number: -

Half-life: -

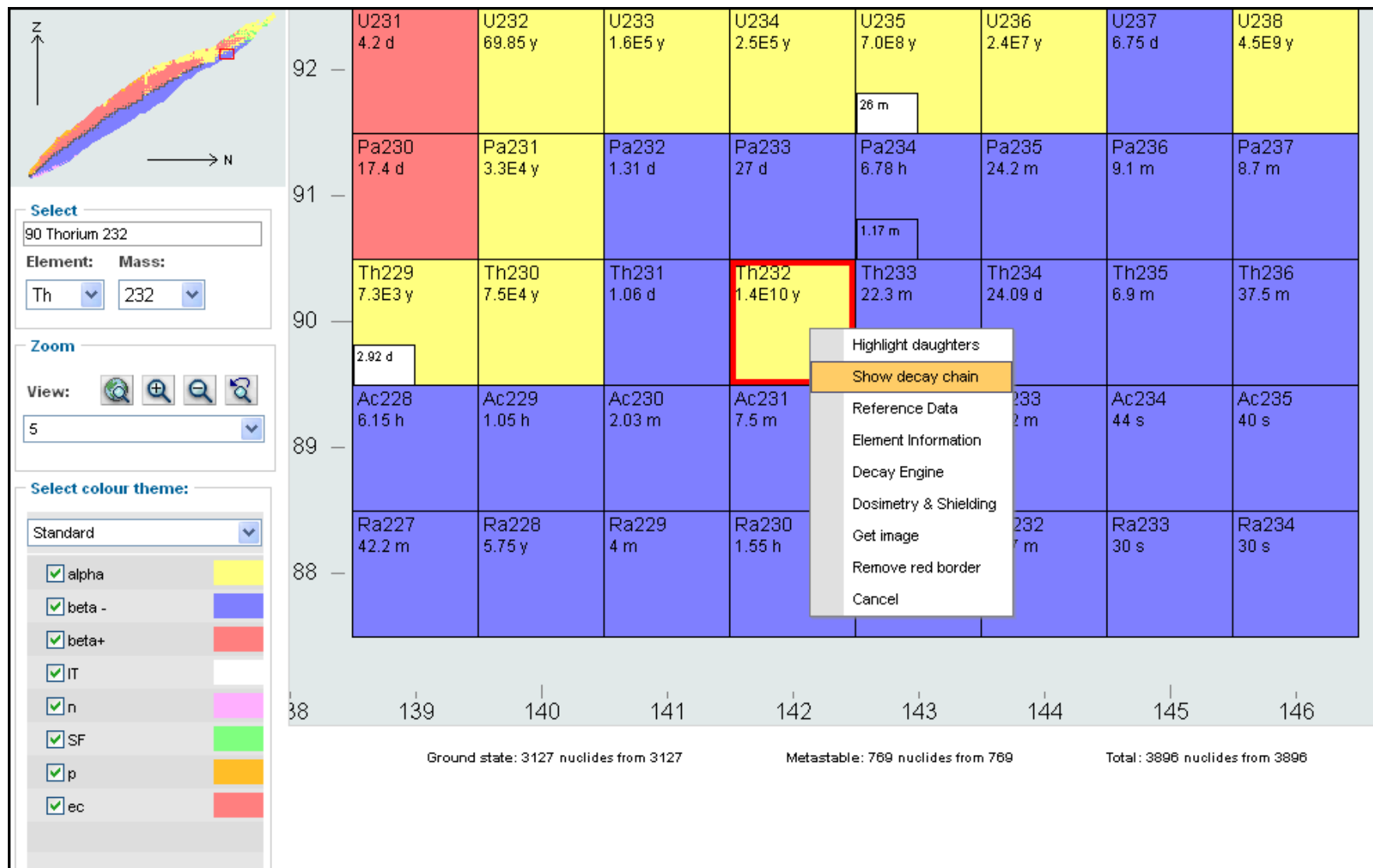
Search returned 6 results
 Number of nuclides (ground + isomeric states): 2

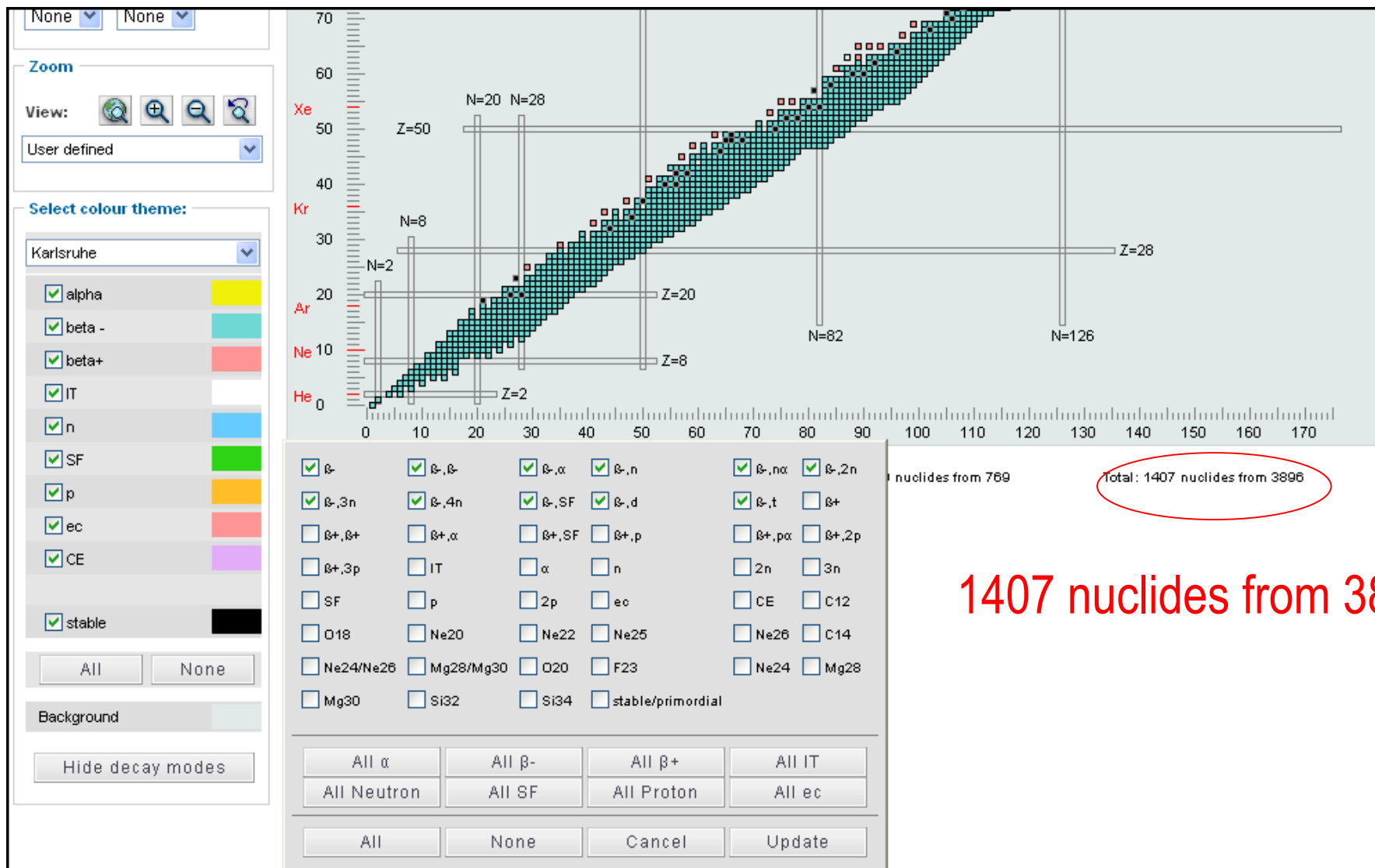
Nuclides	Gamma and X-Rays (keV)	Emission Probability	Half-life
60 Nd 132	299	0.010584	1.47 (± 11) m
60 Nd 132	199.1	0.005292	1.47 (± 11) m
60 Nd 132	99.1	0.009408	1.47 (± 11) m
60 Nd 151	300.58	0.018221	12.44 (± 7) m
60 Nd 151	199.68	0.00266	12.44 (± 7) m
60 Nd 151	100.1	0.0003458	12.44 (± 7) m

☒ Excel ☐ CSV Separator: ☒ Use field qualifier ("")



Try it out! <http://www.nucleonica.net/Applet/universalchart.aspx>





Thanks!

nucleonica

